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Final Report

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On the Physical Processes Underlying the Existence and Origin of X-ray and Mass Loss "Dividing Lines" for Cool Giants and Supergiants

Z. E. Musielak
Center for Space Plasma, Aeronomic and Astrophysics Research
University of Alabama in Hunstville

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SUMMARY OF COMPLETED WORK

This grant was awarded by NASA to The University of Alabama in Huntsville (UAH) to study the physical processes underlying the existence and origin of the coronal/mass loss "dividing line". The physical effects that have been considered in our approach are the necessity of magnetic confinement for hot coronal material and the large reflection efficiency for Alfvén waves in cool exponential atmospheres. Our main goal has been to address the joint problem, namely, how one can account for the coincidence of the relatively sudden onset of large mass loss rates with the equally sudden disappearance of emission associated with high temperature ($> 10^6\ K$) plasma emitting X-rays as one moves along the giant and supergiant branches in the H-R diagram. We have made a significant progress by showing how to construct a plausible and consistent model for the transition from solar-like coronal and transition region behavior to strong, cool mass outflows as evolved stars move across the locus of "dividing lines" in the H-R diagram. The model involves a conjunction of two distinct physical effects: first, the stellar dynamo number drops significantly as the stars despin, and hence classical dynamo activity ceases; second, the large-scale organized surface magnetic flux emergence normally associated with stellar activity disappears, and is replaced instead by small-scale magnetic flux emergence which arises naturally from weak seed fields placed in the turbulent convection zones of these stars. As a result, the atmosphere on large spatial scales becomes largely "open" because of a strong increase in the mean plasma β, and Alfvén waves propagating outwards within the previously confined atmosphere (in which they led to plasma heating, and whence to transition region and coronal emissions) now can reflect on the steep gradient in Alfvén speed, leading to rapid acceleration of the now unconfined plasma. The remaining "closed" structures can no longer remain in the hot coronal state if the spatial scale of these structures falls below the atmosphere's pressure scale height. The result is a cool wind, with relatively low terminal speed and a complete absence of UV and X-ray emissions (Rosner, An, Musielak, Moore & Suess 1991; Rosner, Musielak, Cattaneo, Moore & Suess 1995).

The model described above clearly favors Alfvén waves as a main source of heating the atmospheres to coronal temperatures and as a source of the wind acceleration. Therefore, it is important to understand the behavior of these waves in stellar atmospheres with and without an outflow (e.g., Lou & Rosner 1994). We have used analytical and numerical methods to investigate reflection and trapping of linear and nonlinear Alfvén waves in highly inhomogeneous and expanding stellar atmospheres. Our analytical methods have been primary restricted to wave propagation in atmospheres without a flow. We have calculated the critical frequency for Alfvén waves propagating in stellar atmospheres by using the so-called Klein-Gordon equation approach (Musielak, Fontenla, & Moore 1992; Musielak & Moore 1995) and Dirac equation approach (Alicki, Musielak, Sikorski, & Makowiec 1994). Both approaches have been originally developed by us and used to estimate the height in the atmosphere where the reflection becomes dominant. Presently, we are working on applications of the obtained results to stellar atmospheres with a flow; in particular, we want to apply the results to giants and supergiants. At the same time, we have developed a numerical code to study the propagation of non-WKB Alfvén waves in expanding stellar atmospheres (Krogulec, Musielak, Suess, Nerney, & Moore 1994). We have also calculated the wave pressure accelerating force exerted by linear and Alfvén waves on the atmosphere, and found rather surprising results, namely, WKB Alfvén waves exert much stronger force on the background medium than non-WKB (reflecting) waves. We are presently studying the wave acceleration force in atmospheres of giants and supergiants, and plan to construct models of coronal heating and wind acceleration in these stars. Our studies described above have been also accompanied by numerical calculations of the propagation of nonlinear Alfvén waves and nonlinear pulses in a non-isothermal atmosphere without a flow. The calculations have been performed by Mrs. Huang (a graduate student at UAH, partially supported by this grant) by using a time-dependent, nonlinear, 1-D MHD code developed by Ulmschneider, Zähringer, & Musielak (1991). The obtained results show that a significant part (often up to 60 %) of the energy carried by nonlinear transverse waves is transferred to longitudinal waves due to the nonlinear mode coupling. We have suggested that the resulting heating may be important in heating magnetic regions of stellar chromospheres and in accelerating wind from coronal holes.

Another graduate student (Mrs. Yang Wang) at UAH, who has been actively involved in the research supported by this grant, completed her M.S. research and received her M.S. in December 1993 after presenting the thesis entitled "Studies of Magnetohydrodynamic Waves with Displacement Currents". She has adopted the Klein-Gordon equation approach to investigate the propagation of Alfvén and fast mode MHD waves in a low-density plasma where displacement currents may be important. The obtained results demonstrate that the waves become freely propagating in the region where the displacement currents dominate. These analytical results have been confirmed by numerical calculations also performed by Mrs. Wang.

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